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EVALUATION OF BJTs AS CLOSING SWITCH OF MINIATURIZED MARX GENERATOR

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Abstract

The micro plasma technology is used in various fields such as processing or chemical analysis of minute material, short-wavelength light source, and plasma function device. The plasmas can be generated by an electric discharge. The miniaturized generator was used to produce these plasmas in the micro-scale area. For such background, the miniaturized Marx generator which has Bipolar Junction Transistors (BJTs) as closing switches was developed to generate micro plasmas. In the miniaturized Marx generator, BJTs were operated in avalanche mode to obtain a faster switching speed with ns order. In this paper, three kinds of BJTs which have different collector current each others were evaluated as closing switch. In the experiment, the BJTs were operated in avalanche mode with higher applied voltage (about twice voltage rating) into the between collector and emitter of BJTs. As the result, as Vc increases, the switching time of BJTs which operated in the avalanche mode was decreases. And, the peak of Ic of three kinds of BJTs which operated in avalanche mode was almost same.

I. INTRODUCTION

The micro-plasma has gotten a lot of attention recently, because it can be used for the various applications. The micro plasma is used for chemical analysis or process, short wavelength light source, and the plasma function device. In the field of the micro plasma, the power supply and the system should not be large-scale. Hence, the pulsed power source that part of micro-plasma generating system has been miniaturized.

For such background, the miniaturized Marx generator that uses bipolar junction transistors (BJTs) which operated in avalanche mode as closing switch has been completed in this laboratory. However, the output energy of miniaturized Marx generator is insufficient for the micro plasma generation. Therefore, the output power of miniaturized Marx generator should be large. For such reason, to increase the output energy of miniaturized Marx generator, the BJTs as switching device of miniaturized Marx generator was evaluated.

II. EVALUATION CIRCUIT OF BJT SWITCHING

Figure 1 shows the evaluation circuit of BJT switching. The circuit consisted of a charging resistor (R_{ch}=20 kΩ), a BJT, a capacitor and TTL signal generator. In this work, three BJTs, named 2SC2655, 2SC5076 and 2SC5000 (NPN type Bipolar Junction Transistor, Toshiba, Japan), were evaluated as a closing switch. On the specification sheets of each BJT, three BJTs, used in this work, have the same corrector-emitter voltage (V_{CEO}) of 50V and have the different corrector current (I_C). The I_Cs of 2SC2655, 2SC5076 and 2SC5000 BJTs are 2, 5 and 10 A, respectively. For the evaluation of BJTs, the capacitor was carried from 0.015 to 1.000 μF. In the evaluation, the capacitor was charged up to set-up voltage (V_C) by DC power source (V_{CH}, Cockroft-Walton's circuit, handmade) through the charging resistor. The TTL signal from generator (33220A, Agilent, USA) was applied between the base and the emitter of BJT at 3 pps (Pulsed per second). The V_C and I_C were measured by the high voltage probe (PHV641, PMK, Germany) which is connected between the corrector and the emitter of BJT and the current transformer (Model 2877, Pearson Electronics, USA) which is located on the emitter of BJT (ground), respectively. The signal from the measurement devices were recorded by the digital storage oscilloscope (TDS3034B, Tektronix, USA).

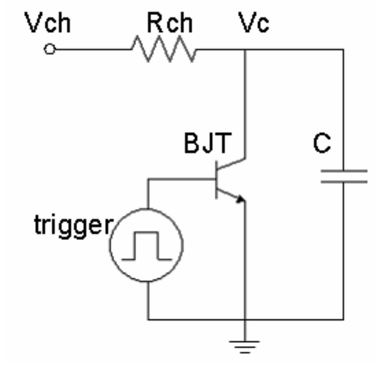


Figure 1. Evaluation circuit of BJT as closing switch.

A. *Onset voltage of leakage current*

Figure 2 shows the dependence of V_C on V_{ch} in the case of using 2SC2655 BJT. The Vc increased linearly with the V_{ch} in the range of 0 to 160 V. Over 170 V of the V_{ch}, the V_C reduced from V_{ch}. This means that the leakage current in the evaluation circuit started flowing when the V_{ch} reached at 170V. In the case of other BJTs (2SC5076 and 2SC5000), the onset voltage of the leakage current flowing were 200 V, respectively. From the results, the evaluations of BJTs were carried out in the range from 0 to the onset voltage of leakage current of V_C.

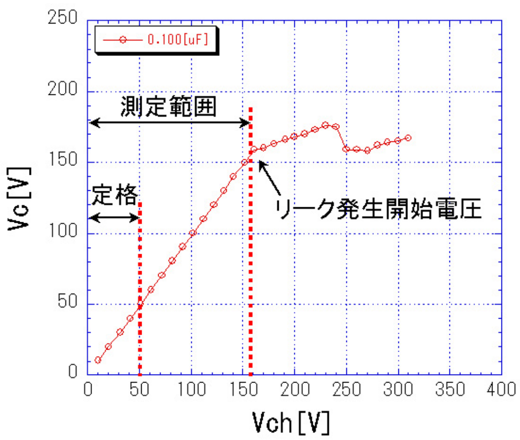


Figure 2. Dependence of V_C on V_{ch}. BJT: 2SC2655.

B. Voltage and current waveforms as switching

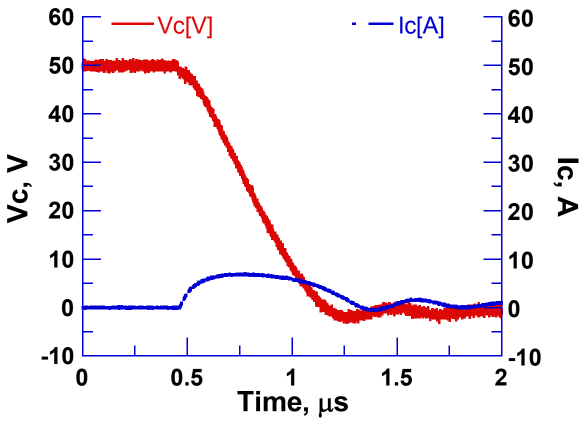
Figure 3 shows the typical V_C and I_C waveforms in the case of using 2SC2655 BJT and 0.1 µF of the capacitor. Figure 3 (a) indicates the waveforms in the operation with 50 V of V_C. On the other hand, Figure 3 (b) indicates the waveforms in the operation with 140 V of V_C. It is observed from Figure 3 (a) that the V_C fell down from 50 to 0 for 0.5 µs. The peak of I_C limited lower than 6 A which is 3 times of specified I_C. Here, it is noted that the switching time was defined as the time duration of the voltage fall time from 90 % to 10 % of V_C. From Figure 3 (a), the switching time of 2SC2655 BJT was 500 nanoseconds. From Figure 3 (b), the V_C fell down from 140 to 0 for 0.15 µs. The peak of I_C is 90 A which is 45 times of specified I_C. The switching time of 2SC2655 BJT was 120 nanoseconds.

Figure 4 shows the I_C waveform in the case of using 2SC5000 BJT and 0.1µF of the capacitor for three different V_C. It is shown from Figure 4 that operation mode of BJT shifts from normal mode to avalanche mode when I_C exceeds the threshold current. The maximum threshold current of BJTs are 7A, 15A and 30A, respectively. This threshold current is about 3 times of specified I_C. And this threshold current is different depending on the V_C. As V_C increase, rise time of I_C is fast, so I_C exceeds the threshold current fast.

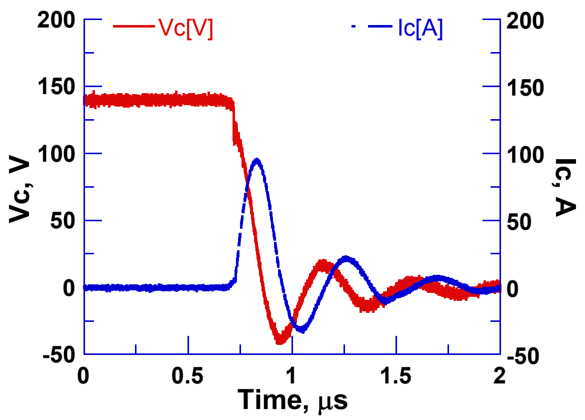
C. Current characteristic

Figure 5 shows the current characteristic as a function of the V_C in the case of using 2SC2655 BJT. In normal mode operation, I_C is limited by the specification of I_C. In avalanche mode operation, I_C increased fast. I_C of BJT which operated in avalanche mode operation as closing switch was given by

$$I_C = V_C \sqrt{\frac{C}{L}} \qquad (1)$$



(a)



(b)

Figure 3. Capacitor voltage waveform (Vc) and collector current waveform (Ic). (a) When BJT was operated in normal mode. (b) When BJT was operated in avalanche mode.

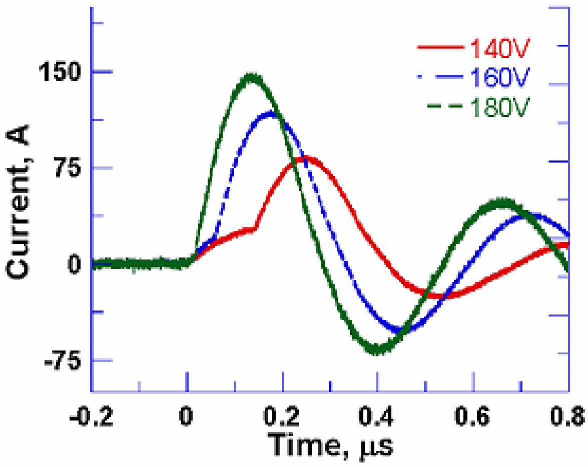


Figure 4. Collector current waveform for three different Vc (2SC5000, C=0.100uF).

where C is capacitance, and L is circuit inductance. This relational expression is clear from Figure 5. Because, in avalanche mode operation, I_C is proportional to V_C or square root C. Another characteristic in this test, V_C decreases when the capacitor increases. This is clear from that the threshold to shift to avalanche mode operation is almost constant and the equation (1).

Figure 6 shows the comparison of the current characteristic as a function of V_C. When BJT was operated in normal mode operation, I_C of each BJT has the 5 times difference. However, in avalanche mode operation, I_C of each BJT is almost same. Hence, the specification of I_C is not important to use BJT as switching device of Marx generator.

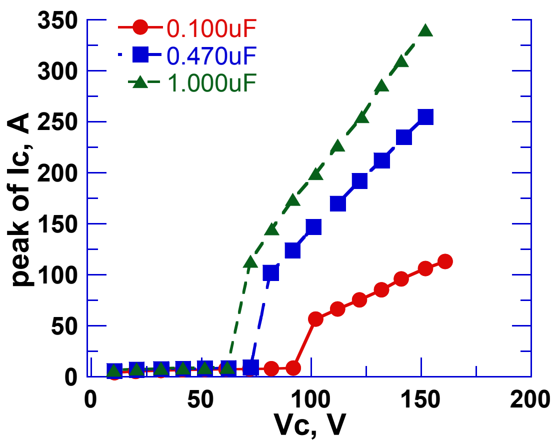


Figure 5. Current characteristic as a function of Vc.

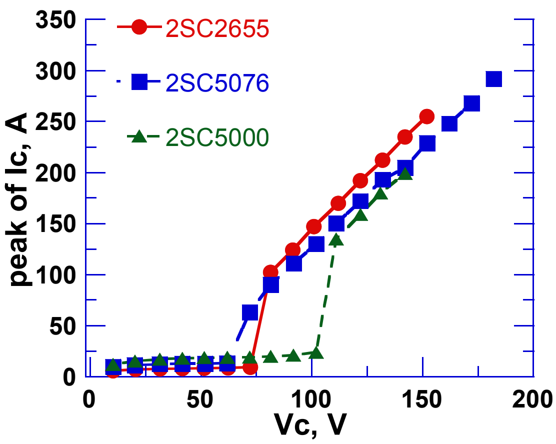


Figure 6. Comparison of the current characteristic as a function of Vc.

D. Switching time characteristic

Figure 7 shows the switching time characteristic as a function of the V_C in the case of using 2SC2655 BJT. In normal mode operation, as V_C and C increase, the switching time is increased. In this case, I_C that flow in the BJT is limited by the specification of I_C. Therefore, when the quantity of electric charge ($Q=V_CC$) is large, the switching time is increased.

In avalanche mode operation, as capacitance is increased, the switching time is increased. However, the switching time is increased as V_C decreases. As discussed previous, I_C exceeds the threshold current fast as the voltage is high, and then it shifts into avalanche mode operation.

Figure 8 shows the comparison of the switching time characteristic as a function of the V_C. It is shown from figure 8 that 2SC2655 is the faster than other BJTs. Because the specification of I_C 2SC2655 is smaller than another BJTs, its threshold current that shifts into avalanche mode is most small. Hence, 2SC2655 shifts into avalanche mode fast. In a word, the switching time is fast. The difference of this shift time greatly influences the switching time characteristic. Because the delay to avalanche mode operation of 2SC2655 is most small, it is the suitable as the switching device in the Marx generator.

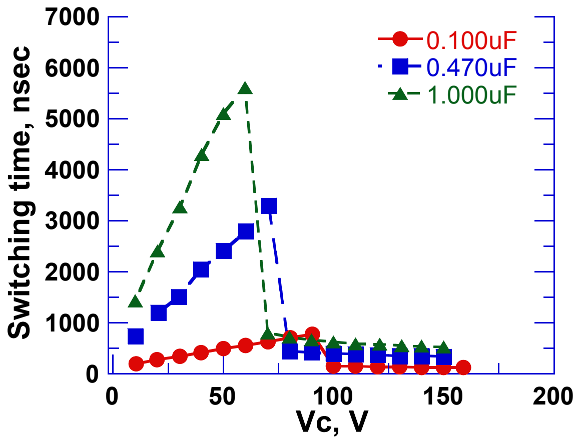


Figure 7. Switching time characteristic as a function of Vc.

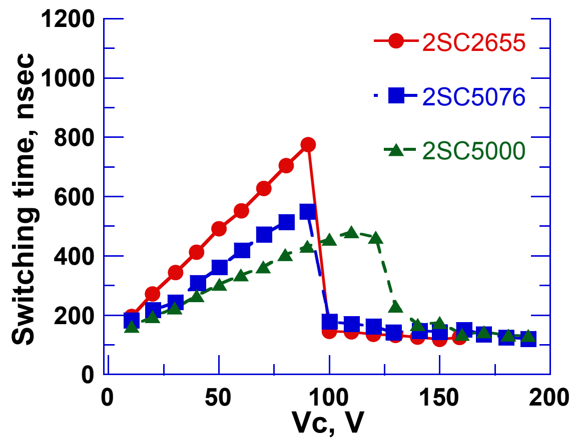


Figure 8. Comparison of the switching time characteristic as a function of Vc.

E. Impedance waveform

Figure 9 shows the impedance of BJT that calculated from V_C and I_C waveform. The impedance of BJT which operated in avalanche mode operation decreases faster than impedance waveform which operated in normal mode (see Figure 9).

Figure 10 shows the comparison of three kinds of BJTs of impedance of BJT. It is shown from Figure 10 that 2SC2655 was decreased rapidly compared with other BJTs.

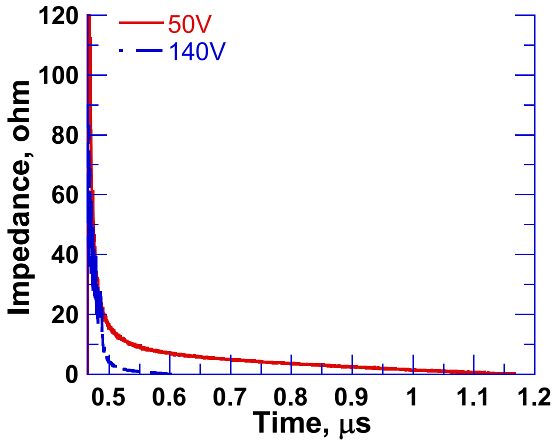


Figure 9. Impedance waveform(2SC2655).

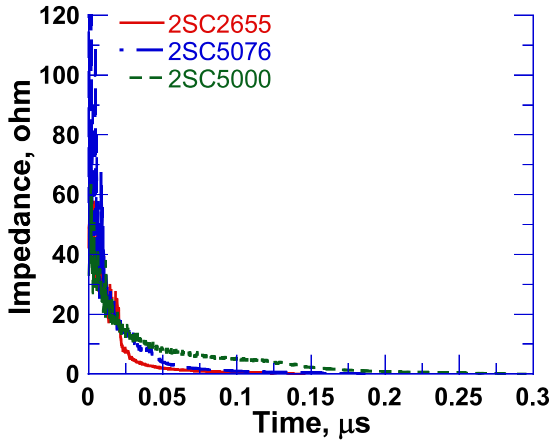


Figure 10. Comparison of impedance waveform.

III. SUMMARY

In this research, to select suitable BJT for switching device of the miniaturized Marx generator which has large energy, the characteristic of BJT was evaluated. As the results, when IC exceed the threshold current, operation mode of BJT shifts from normal mode to avalanche mode. And even if specification of BJT is different, the IC of BJT is almost the same. As the results of switching time characteristic test, it is shown that 2SC2655 is suitable as the switching device of the miniaturized Marx generator. Because the shift to avalanche mode from normal mode operation is faster than others.

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